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Lead-Cooled Fast Reactor (LFR)

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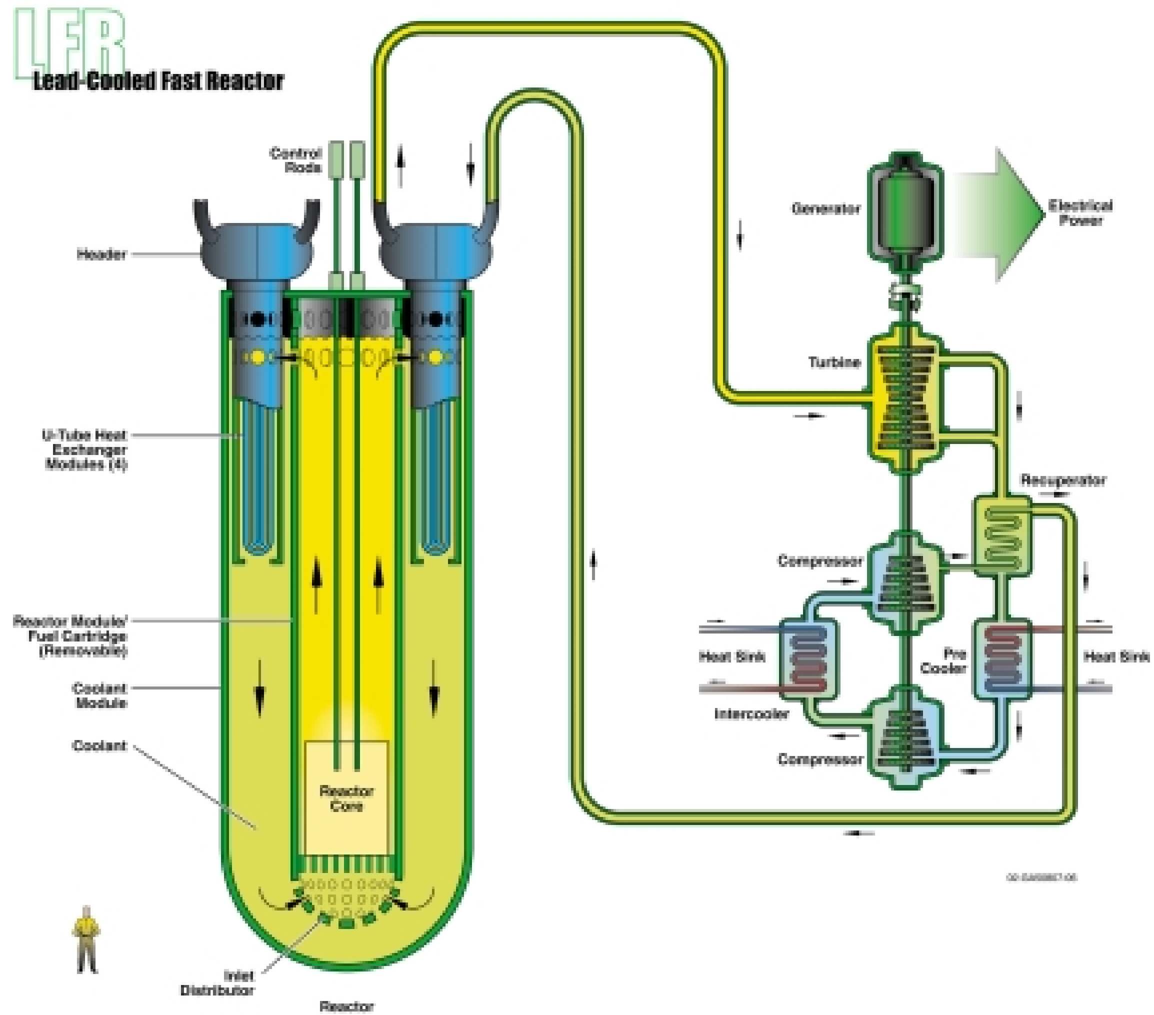
Lead-Cooled Fast Reactor (LFR)



Characteristics

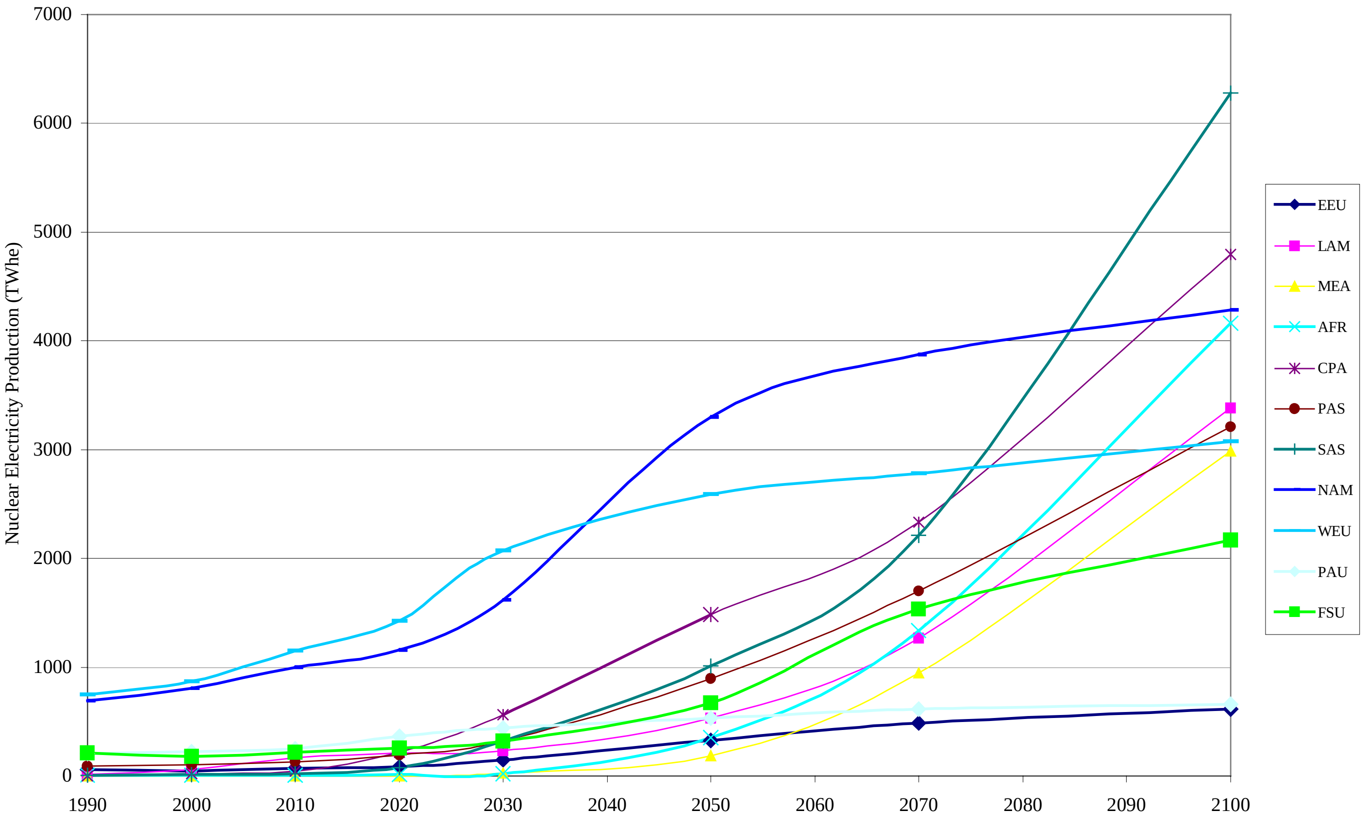
- ***Pb or Pb/Bi coolant***
- ***550°C to 800°C outlet temperature***
- ***Fast Spectrum***
- ***Multi-TRU recycle***
- ***50–1200 MWe***
- ***15–30 year core life***

Intrinsic Features of Lead Alloy

- ***Low Neutron Absorption and Slowing Down Power***
  - ***Allow to open the lattice, increase coolant volume fraction absent a neutronics penalty***
  - ***Facilitates natural circulation***
- ***High Boiling Temperature at Atmospheric Pressure (~1700°C)***
  - ***Unpressurized primary (precludes loss of coolant accident initiator)***
  - ***Margins are available to employ passive safety – based on thermo/structural feedbacks***
  - ***Potential to raise core outlet temperature (~800°C suitable for H_2 production and other process heat missions)***
- ***Non-vigorous reaction with air and water***
  - ***Potential to simplify heat transport circuits***
  - ***Potential to simplify refueling approaches***

Electricity Production Mission

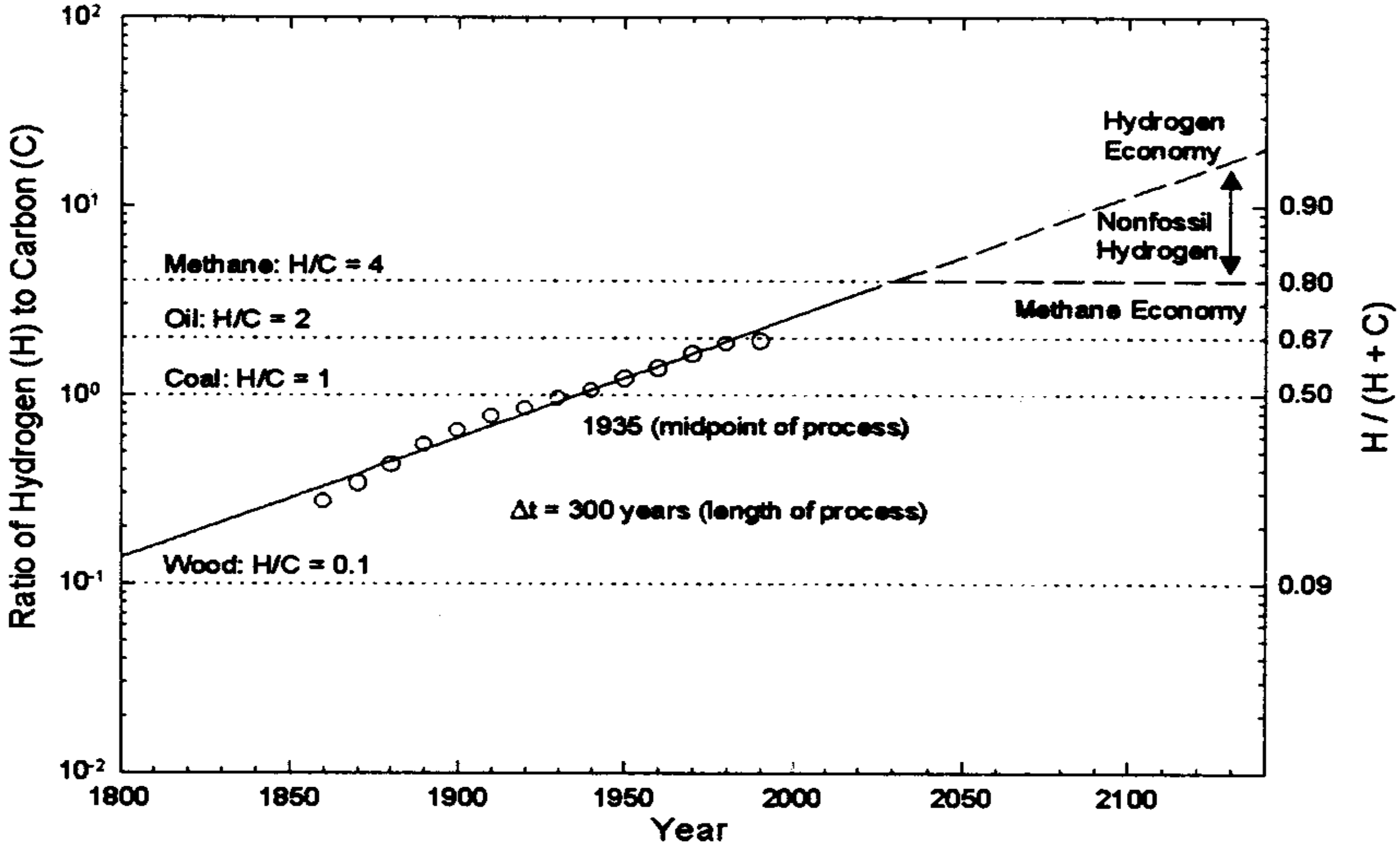
- ***Sustainable electricity production using fissile self-sufficient closed fuel cycles***



Rapid Growth in Developing Countries

EEU = Central & Eastern Europe; LAM = Latin America; MEA = Middle East & North Africa; AFR = Sub-Suharan & Southern Africa; CPA – Centrally Planned Asia & China; PAS = Pacific OECD (Japan, Australia, New-Zealand); SAS = South-East Asia; NAM – North America; WEU = Western Europe; PAU = Other Pacific Asia; FSU = Former Soviet Union

Trend Toward Low Carbon Energy Sources



Ratio of hydrogen (H) to carbon (C) for global primary energy consumption since 1860 and projections for the future, expressed as a ratio of hydrogen to carbon (H/C). SOURCE; Ausubel (1996) and Marchetti (1985).

Established Markets

- Established Market Features
  - Extensive electricity grids
  - Fuel cycle support infrastructures in place
  - Large scale financing available
- Large Monolithic and Modular Concepts
  - 1200 MWe Monolithic (economy of scale strategy)
  - ~300 MWe modular (economy of just-in-time capacity additions)
- Fissile self sufficient or net TRU burners
- Targeted primarily to electricity markets (regulated or deregulated) in industrialized countries
- Financial conditions may require high interest/quick return on capital (modular plants)

Developing Markets

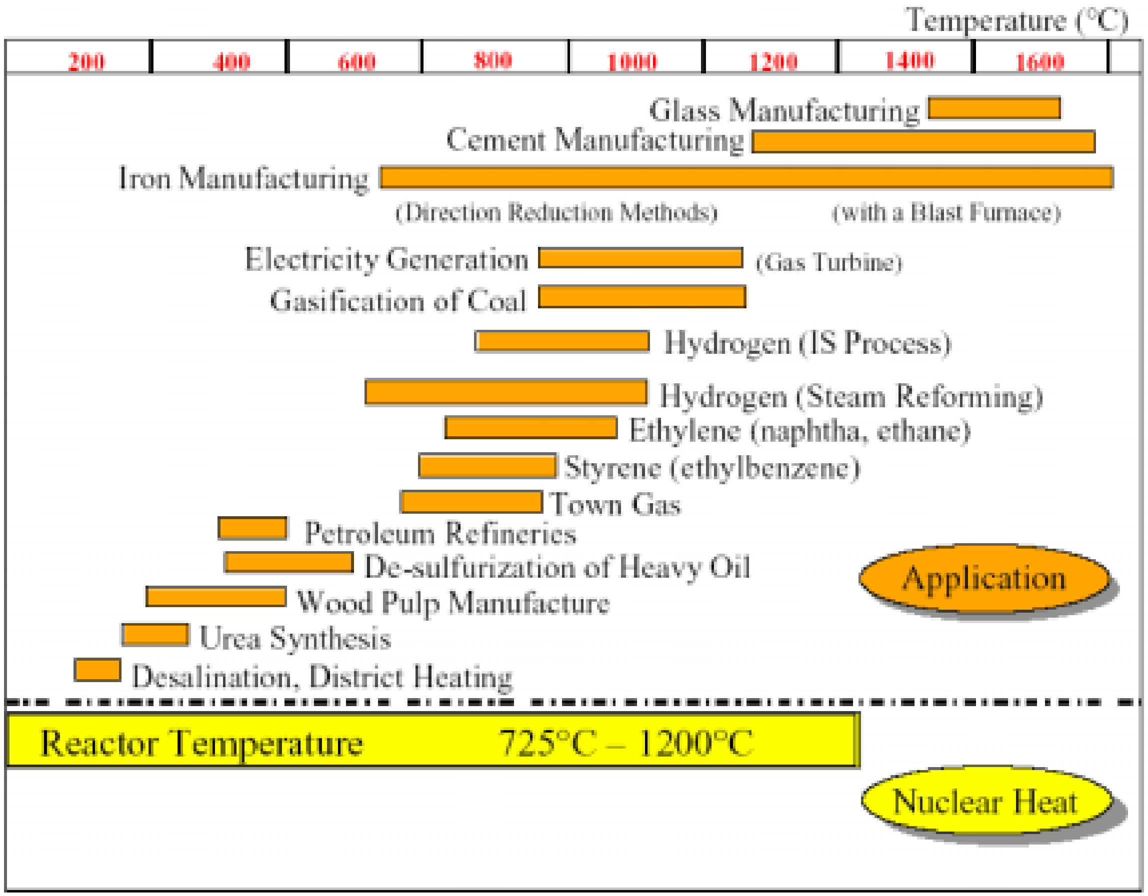
- *Small or sparse grids or developing countries lacking an indigenous fuel cycle infrastructure and tight capital availability*
  - *~50-150MWe "Battery" (Economy of Mass Production)*
    - *De-rated power density (LWR range) (natural circulation cooled)*
    - *Passive load follow/passive safety (no safety functions for BOP)*
    - *Long refueling interval: 15-20y with an internal conversion ratio ~1.0*
    - *Limited Staffing*
    - *Transportable*
      - *Factory built turnkey plant*
      - *Rapid installation & revenue generation*
      - *Cassette or entire module refueling-no refueling equipment on site*

Developing Markets

- ***Regional fuel cycle centers offering front & back end services with operation under International Nonproliferation Oversight***
  - ***No Interest (or capacity) to emplace a full fuel cycle infrastructure***
  - ***Nonproliferation advantages due to localized international oversight of bulk fuel and waste management***
- ***Resulting institutional Issues and paradigm shift***
  - ***Supplier assumes risk of supplying large quantities of a commodity product; client risk is reduced***
  - ***International consensus needed for acceptability of regional fuel cycle centers – which also include waste management***

Extended Energy Products Mission

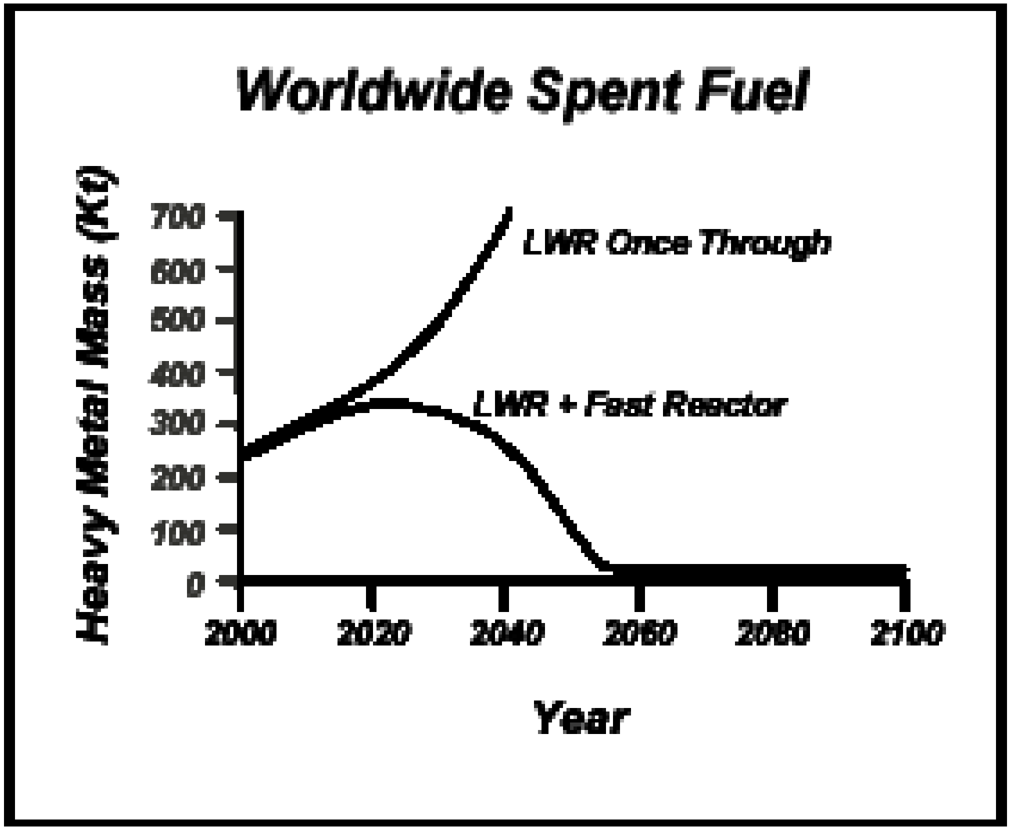
- ***Higher temperature (~800°C) operation for hydrogen manufacture***
- ***Desalinization bottoming cycles for potable water***



•Links clean sustainable nuclear resource to clean emission free fuel (H_2)

Actinide Management Mission

- *Symbiotic Fuel Cycles*
  - *Fast burner reactors for fission consumption of TRU from open cycle thermal reactors*

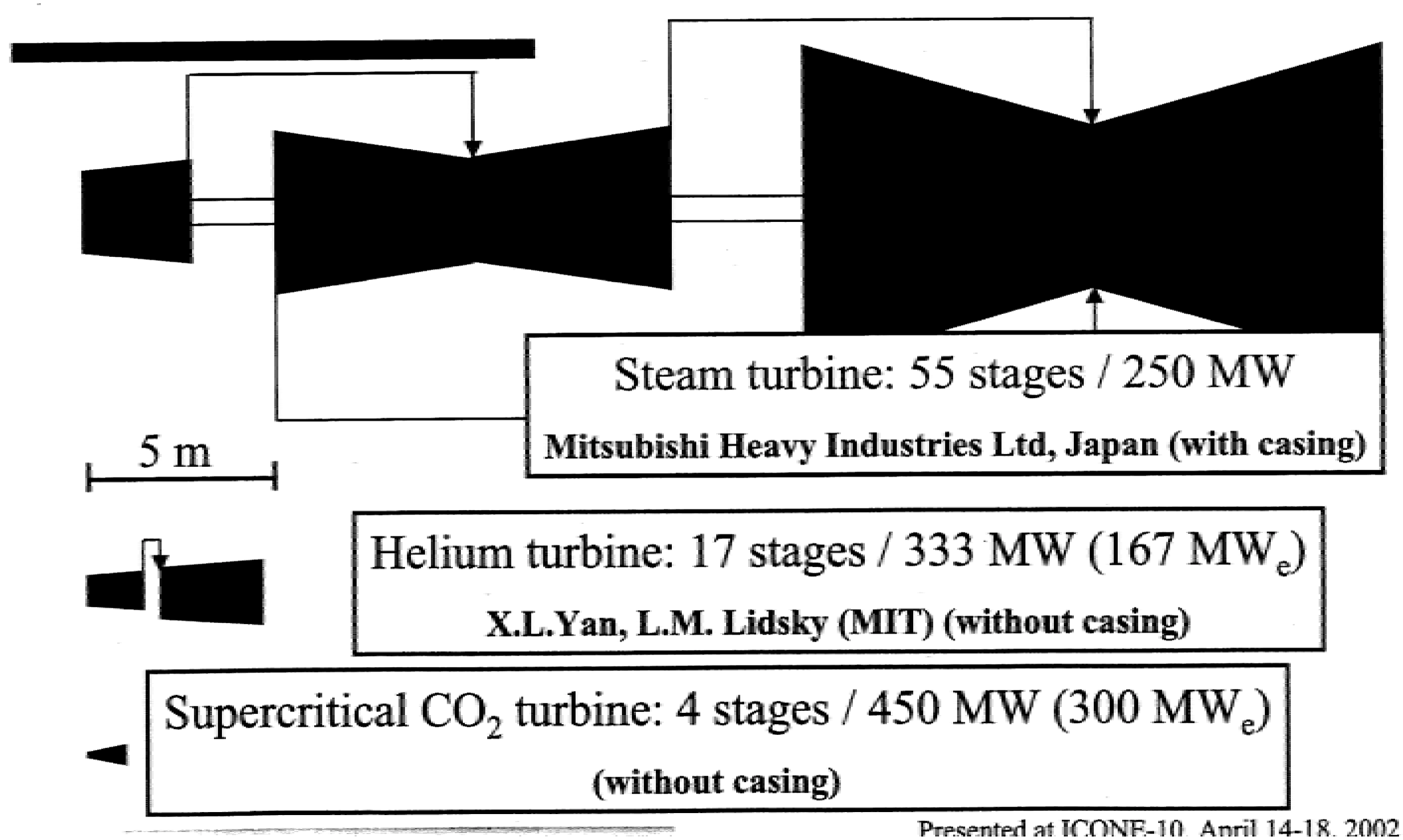


Power Plant Innovations

- *Heat Transport*
  - *Natural circulation at full power (open lattice, low power density)*
  - *Lift pump*
  - *Direct contact heat exchange*
  - *Direct contract steam generation*
  - *Copper or liquid metal bonded steam generation design*
- *Plant Control*
  - *Passive load following:*
    - *Zero burnup control swing, internal conversion ratio of one*
  - *Feedbacks innately adjust power to heat request from BOP*

Power Plant Innovations

- *Energy Converters*
  - *Supercritical CO_2 Brayton Cycle*
  - *Supercritical Rankine Cycle*



Fuel Cycle Innovations

- ***Advanced aqueous or pyroprocess recycle technology with intrinsic nonproliferation features***
  - ***Produces co-mixed Pu+MA feedstock (no separated Pu)***
  - ***Incomplete fission product separation***
- ***Fuel Cycle Support Facilities Options***
  - ***Co-located***
  - ***Regional***
- ***Multiple Fuel Options***
  - ***Fuel types TRU/U/Oxide, TRU/U/Nitride, TRU/U/Alloy, TRU Alloy, MA Alloy***
  - ***Remote refabrication technology depends on fuel type***
    - ***Simplified pelletization (oxide, nitride)***
    - ***Vibrocompaction (oxide, nitride)***
    - ***Injection casting (metal)***

Enabling R&D-Materials

- Structures and Cladding: Corrosion control, radiation stability, and fuel compatibility
  - Ferritic-martensitic steels (550°C concepts)
  - Ferritic-martensitic ODS (550°C + concepts)
  - Si C or Zr N composites or coatings (800°C concepts)
  - Vanadium or other refractory metal alloys (800°C concepts)
- Heat Exchangers : Tube Interfaces

Pb or Pb-Bi/steam	and	HBr + Steam / Steam
/ SC CO_2		/ CO_2
/ He		/ He
/ Molten Salt		/ Molten Salt

- Fabricability of structural materials

Enabling R&D-Fuel cycle

- *Nitride Fuel: High potential for lead alloy concept mIssions*
  - *Compatible with Pb and good to high temperature*
  - *High density; high thermal conductivity to enable passive safety*
- *Required R&D*
  - *N15 enrichment and recovery during recycle*
  - *Pyro recycle/in-situ front end dissolution, and back end re-conversion*
  - *Vibropac remote refabrication*
  - *Fuel/Clad/Coolant Performance Testing*
    - *Properties: unirradiated; irradiated*
    - *Normal & operational transient testing*
    - *Upset condition testing*
    - *Severe event phenomenology testing*

Enabling R&D-Energy Conversion

- ***Supercritical CO_2 Brayton Cycle***
  - ***Thermodynamic optimization***
  - ***Recuperator design, IHX design***
  - ***Turbine design***
- ***Ca-Br Water Cracking***
  - ***Materials***
  - ***Ca support***
  - ***Properties of reactants***
  - ***Rate constants***
  - ***Flowsheet/bench scale/prototype***
- ***Desalinization Bottoming Cycle***
  - ***Overall BOP heat balance***
  - ***Optimized hybrid cycles***

Summary

- *Fast Spectrum, closed TRU-Multi recycle fuel cycles*
  - *Operate as fissile self sufficient*

  or
  - *Operate as TRU burners in a symbiotic nuclear energy park*
- *Power Plants Display*
  - *Range of sizes 1200 MWe, 300 MWe, 50-150MWe*
  - *Extensive innovation in*
    - *Heat transport*
    - *Energy conversion*
- *Special emphasis on expanding client base:*
  - *Developing country markets*
  - *New energy products (H_2, Water)*

Summary

- ***Institutional Innovations will be Needed for the Battery Concepts***
  - ***Economy of mass production***
  - ***Regional fuel cycle facilities***
- ***Extensive R&D will be required***
  - ***Fuel/clad/coolant combinations currently have only sparse database***
  - ***New recycle/refab required for new fuel (nitride, fertile-free for burners)***
  - ***New energy converters require development***

Backup

Ca-Br Cycle

- 4-Step Thermochemical Cycle

		Temp (°C)	Heat Flow	Purpose
1.	Ca Br_2 (s) + H_2O (g) ® CaO(s) + 2HBr(g)	700-750	in	Crack water with Ca Br_2 and heat
2.	Ca O(s) + Br_2 (g) ® Ca Br_2(s) + ½ O_2(g)	500-600	~ neutral	Regenerate $CaBr_2$ using Br_2
3.	Fe_3O_4(s) + 8H Br(g) ® 3Fe Br_2(s) + $4H_2O$(g) +Br_2(g)	200-300	out	Regenerate Br_2 using rust
4.	$3FeBr_2$(s) + $4H_2O$(g) ® Fe_3O_4(s) + 6HBr(g) + H_2(g)	550-600	in	Regenerate rust using water & heat

- H_2 released in Step 4: O_2 released in Step 2
- Heat Supplied at ~725°C in Step 1 and at ~575°C in Step 4